Hydrological Drought Assessment in the Southeast Part of the Czech Republic

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Abstract
The paper deals with the temporal-spatial analysis of the hydrological drought in the southeast part of the Czech Republic (i.e. South Moravia) on the selected watergauge stations which conclude the catchment areas of the main rivers in the territory mentioned. The main purpose of this paper consists in assessing the hydrological drought according to the applied method. The method of the hydrological drought elaboration without any fixed delimitation values of low discharges and their duration was presented and used. The mean annual runoff distribution and the occurrence of low discharges were studied.

Key words
Hydrological drought, flood, dry period, drought zone, temporal-spatial analysis, watergauge station, catchment, runoff, low discharge, M-day discharge, mean minimum t-day discharge, mean minimum t-day runoff, drought duration, rate of runoff, exceedance probability, limit of low discharge, hydrological year, mean monthly minimum discharge, dry and extremely dry hydrological year.

1. Introduction

The recent period of global warming is characterized by the increased occurrence of natural extremes. It is also valid for watercourses with the occurrence of hydrological droughts and floods. The hydrological extremes present a problem not only in the Czech Republic and in Europe but all over the world. The disastrous floods in the Czech Republic in July 1997 and in August 2002 reached peak discharges with the return period exceeding 100 years and more. On the other hand, dry periods occurred in the Czech Republic, for example, at the beginning of the 1990s. The year 2003 was also extremely dry. The areas with the annual precipitation total less than 500 mm can be considered drought zones in the Czech Republic. These areas are located mainly in the southeast part of the country.

2. Data and selection of the territory studied

Thirteen watergauge stations from the CHMI database were selected for the analysis with series of mean daily discharges from the period of 1981-1990. One station finished its observation in 1988. The territory of interest (Fig. 1) is represented by the Dyje and Morava River catchments in their final parts which are located in the southeast part of the Czech Republic (i.e. South Moravia). The total runoff from all analysed stations was registered in final section of the watergauge station Moravsky Jan in the Slovak Republic near the confluence of the Dyje and Morava Rivers.

3. Methodology

Hydrological conditions of the area were studied and mean annual runoff distribution was determined and described. In the mean annual runoff variation, runoff values related to particular months, seasons and half-years were calculated.

For the hydrological drought evaluation, a suitable delimitation of low discharges and their duration in the chosen watergauge stations was established. It is possible to choose a fixed delimitation, according to Netopil, R. et al., (1984), for instance, who proposed 36% of long-term mean annual discharge Q_a. As it follows from the works of Sklenar, J., 1993, 2000, a suitable quantile of M-day discharges can be considered more convenient for the choice of delimitation than the fixed value because M-day discharges correspond better with individual characteristics of the given watercourse. The method of the hydrological drought assessment was suggested. The mean minimum t-day discharges of continuous duration t = 1, 2, 3 - 10 and 30, 60, 90 days were calculated. Also M-day discharges Q_{270}, Q_{330}, Q_{355}, $Q_{99\%}$, Q_{364} were used. The values of the mean minimum t-day runoff of continuous duration t in the range of 1, 2, 3 - 10 and 30, 60, 90 days were obtained by converting above mentioned mean minimum t-day discharges. Also M-day discharges had to be converted into runoff units. This conversion is the key element of the applied method presented in this paper. From the compiled charts (Fig. 2, Fig. 3), the numbers of days needed for reaching the values of certain quantile of M-day discharges, chosen in advance, were determined. (Fig. 5-7, Tables 2-4). The hydrological drought was evaluated according to the detected number of days. Numbers of events when the proper M-day discharge was not reached or was not decreased were taken into account as well.

The temporal occurrence of the hydrological drought and drought duration were studied. As for a fixed limit of drought duration, the minimum period in which discharges decrease below Q_{355} can make 3 days (Netopil, R. et al., 1984) or 4 days (Cerkasin, A., 1964). In this paper, the assessment of mean minimum t-day discharges of continuous duration t = 1, 2, 5, 10, 30, 60 and 90 days was performed. Dry years were determined by rate of runoff during hydrological years in using the values calculation of exceedance probability according to Cegodajev formula (in Netopil, R. et al., 1984).

4. Results

As it results from the analysis of the mean annual runoff distribution (Fig. 4, Table 1), the minimum runoff values were recorded in all watergauge stations in the range of 1.9%-4.8% of the mean annual runoff R_a, mostly in September, occasionally in October. It is in autumn season in the Czech Republic when resources of underground water are usually reduced after vegetation season. In the relative annual variation, the lowest runoff 1.9% of R_a fell on September in Petrov station with a smaller catchment area of 41.40 km^2. The second lowest monthly runoff value (2.2% R_a) was observed in the same station in October. On the contrary, the maximum runoff values were recorded in all stations in March (16.8 % of the mean annual runoff R_a on the average). The March runoff is formed in consequence of spring snow melting. The highest runoff value 19.5% of R_a was observed in Osvetimany and Petrov stations with the small catchment area (Osvetimany 9.54 km^2). The second highest monthly runoff occurred in April, less often in February. On the average, 13.3% of the mean annual runoff R_a flowed away in the course of autumn months (September, October, and November) whereas 39.1% of Ra flowed away, on the average, within spring months (March, April, and May). With respect to high evapotranspiration, the runoff values in the course of vegetation season were lower (46.2% R_a) than during the remaining half-year. The vegetation season lasts from April to September in this country.

Q_{270} can be considered too high limit of low discharges. Totally 36 to 90 days were needed to achieve the value Q_{270}. Moreover, this value was not reached in 53% of events. (Table 5) Quantile Q_{364} is the discharge value which is not reached 1 day in the statistically average hydrological year. The value of quantile Q_{364} appeared too low because discharges did not decrease below this value in 85% of events. The numbers of days for reaching Q_{364} were never higher than 1 day in evaluated events. Discharges $Q_{99\%}$ and also Q_{355} as the limits of low discharges duration can be considered the most convenient from the viewpoint of the M-day discharges. It was evident that a higher number of days was necessary to achieve the limit represented by M-day discharges in the years with lower discharges than in the year with higher discharges. The higher was the limit of low discharges, the more days were needed to reach it. $Q_{99\%}$ is the discharge corresponding with the value of exceedance probability equal to 99%. The number of days for reaching this value ranged from 1 to 18 , from 1 to 42 for Q_{355} and from 5 to 79 for Q_{330}. The hydrological drought assessment depended not only on the value of a selected limit but also on the rate of runoff in a proper hydrological year and on the catchment area. The number of days for reaching quantile $Q_{99\%}$ varied between 4 and 18 days (9 and 42 days for Q_{355}) in the years with the lowest discharges, between 1 and 5 days (up to 22 days for Q_{355}) in the years with the largest discharges. I found out that more days in smaller catchments in the case of years with lower discharges were necessary for reaching limit discharges than in larger catchments. On the contrary, the numbers of days in the case of years with larger discharges in smaller catchments were lower. Hereby, the extremes of hydrological regime on watercourses occurred more considerably in smaller catchments. Smaller catchments indicated water capacity in the given area. If drought periods arise, greater impacts on the rate of runoff in watercourses will be observed in catchments with smaller area.

Low discharges occurred in the course of summer and autumn months, mostly in August and September, but these could be observed in November, December, sometimes in January in some hydrological years (Fig. 8-9). The low discharges were never observed in the period from March to May, in February and June rarely. In most cases, low discharges of longer duration (30, 60, 90 days) included low periods of shorter duration (1,2 days) but it was not valid in all cases. In consequence of the above fact, isolated minimum discharges were determined. In some cases, a longer duration of the hydrological drought was documented by continuing low discharges occurrence in the following hydrological year (the end of 1983 and the beginning of 1984, for example). Charts were completed by histograms of mean monthly minimum discharges $Q_{m,\ min}$ which correspond very well to the periods of low discharges. The example of watergauge station Ivancice (Table 6) shows the rate of runoff of hydrological years 1981-1990 and also extremely dry and dry hydrological years during 1981-2007 in descending order from the driest year 1991 (exceedance probability p=99.2%) observed in this station at all (Table 7). The second driest hydrological year 1990 was evaluated with p=98%. Three years were extremely dry and 9 years dry in Ivancice in the period 1981-2007.

5. Conclusion

Considering the favourable temperature conditions and fertile soil, the southeast part of the Czech Republic is the most productive agricultural region of the country. Nevertheless, periods of drought affect this region very often. Therefore, the research, monitoring and assessment of drought remain an up-to-date topic. The hydrological drought analysis method without any fixed delimitation of the low discharges was presented in this paper. The advantage of this method consists in possibility of choosing the suitable limit of the low discharges in advance. The hydrological drought can be assessed with respect to the selected limit discharge. The paper should contribute to a better understanding of the hydrological drought.

References :

Cerkasin, A. (1964) : Hydrologicka prirucka. (Hydrological guide book). Hydrometeorological Institute, Praha, 224 pp.

Brazdil, R. - Kirchner, K. et al. (2007) : Vybrané prirodni extremy a jejich dopady na Morave a ve Slezsku. (Selected Natural Extremes and their Impacts in Moravia and Silesia). Masaryk University Brno, Czech Hydrometeorological Institute Praha, Institute of Geonics Ostrava, Academy of Sciences of the Czech Republic, 431 pp.

Nemec, J. - Hladny, J., eds. (2006) : Voda v Ceske republice. (Water in the Czech Republic). Published by Consult for the Ministry of Agriculture of the Czech Republic, Praha, 253 pp.

Netopil, R. et al. (1984) : Fyzicka geografie I. (Physical Geography I). SPN, Praha, 272 pp.

Roznovsky, J. - Litschman, T., eds. (2004) : Extremy pocasi a podnebi. (Weather and Climate Extremes). Abstracts proceedings from the international workshop. Published by the Czech Hydrometeorological Institute for the Czech Bioclimatological Society, Brno, 42 pp.

Sklenar, J. (1993) : Hydrologicke pomery jizni Moravy v obdobi 1981-1990 se zretelem k analyze sucha. (Hydrological Conditions in Southern Moravia during 1981-1990 with Respect to the Analysis of Hydrological Drought). M.Sc. thesis. Faculty of Science, Masaryk University, Brno, 178 pp.

Sklenar, J. (2000) : Hydrological Droughts in Southern Moravia – presentation. 9th International Postgraduate Course in Hydrometeorology, Tel-Aviv.

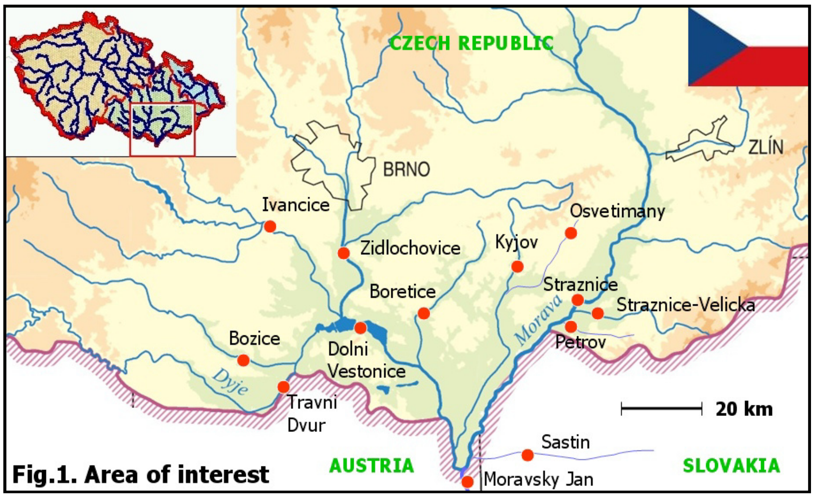

Fig.1. Area of interest

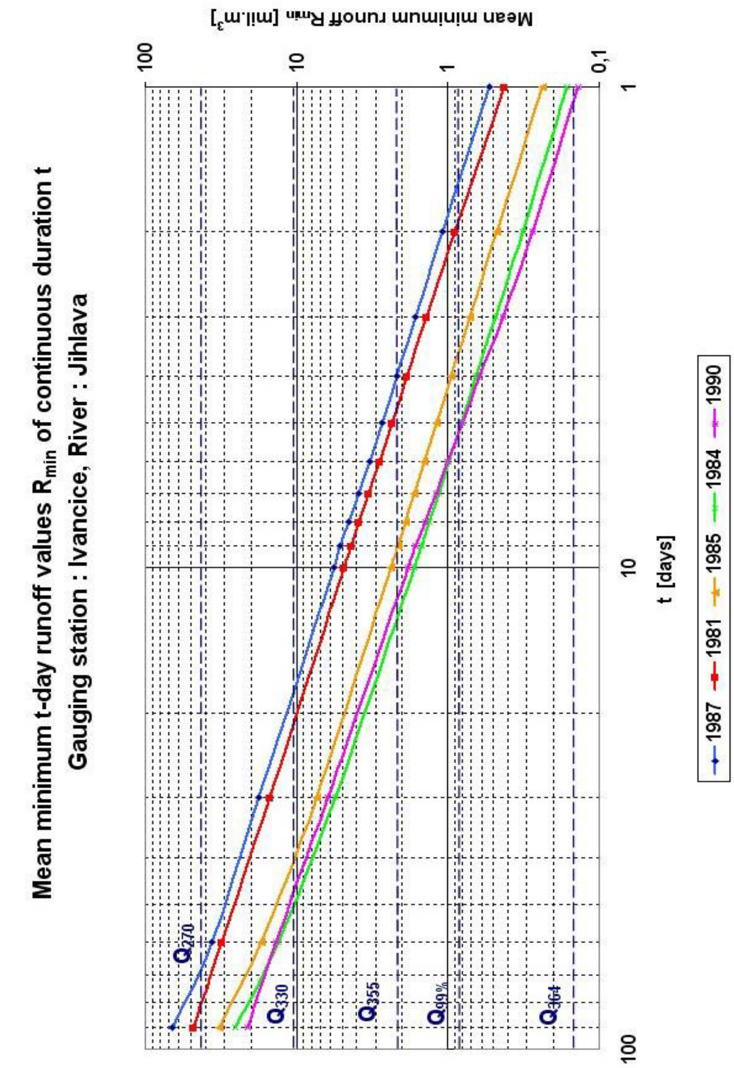

Fig. 2. Mean minimum t-day runoff values R_{min} of continuos duration t.
Station : Ivancice, River : Jihlava

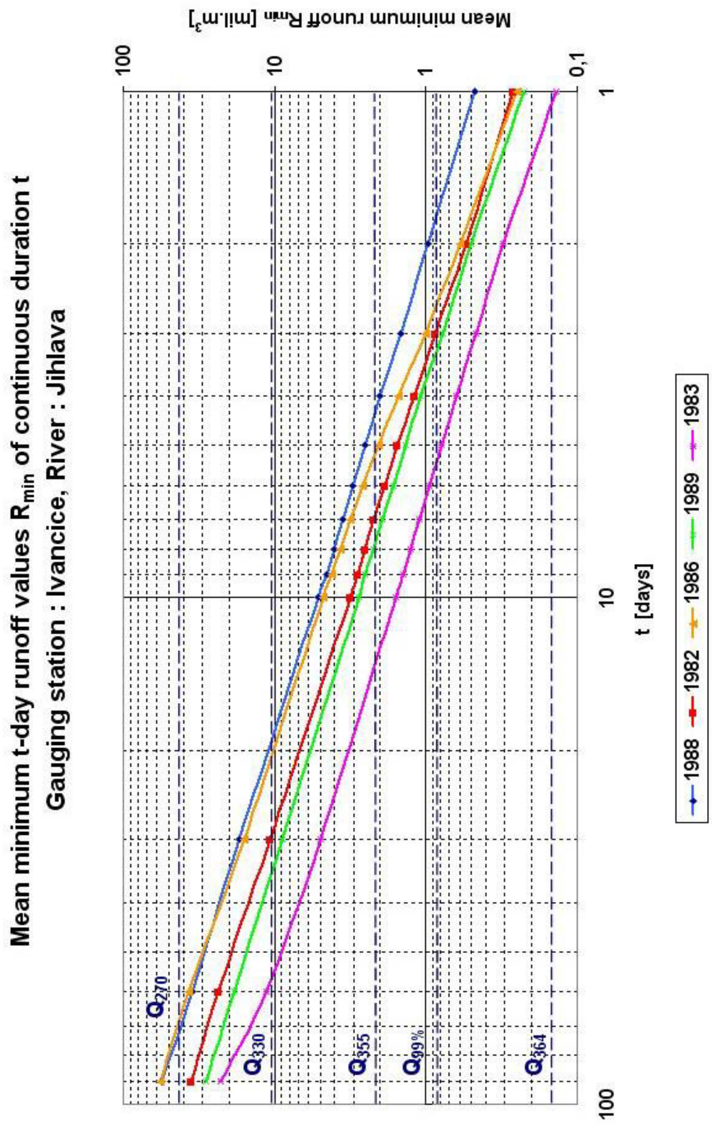

Fig. 3. Mean minimum t-day runoff values R_{min} of continuos duration t.
Station : Ivancice, River : Jihlava

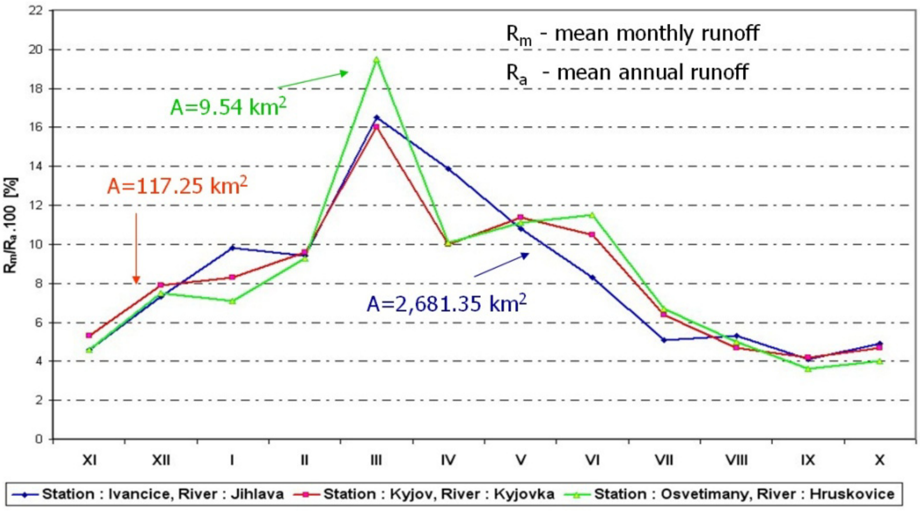

Fig. 4. Mean annual runoff distribution (relative)

Table 1. Mean annual runoff distribution (relative)

Month	Station : Ivančice River : Jihlava			Station : Kyjov River : Kyjovka			Station : Osvětimany River : Hruškovice			Month
	$R_m/R_a.100$ [%]	Seasonal runoff [% R_a]	Half year runoff [% R_a]	$R_m/R_a.100$ [%]	Seasonal runoff [% R_a]	Half year runoff [% R_a]	$R_m/R_a.100$ [%]	Seasonal runoff [% R_a]	Half year runoff [% R_a]	
XI	4.6			5.3			4.6			XI
XII	7.3			7.9			7.5			XII
I	9.8	26.5	52.5	8.3	25.8	51.8	7.1	23.9	52.0	I
II	9.4			9.6			9.3			II
III	16.5			16.0			19.5			III
IV	13.9	41.2		10.0	37.4		10.1	40.7		IV
V	10.8			11.4			11.1			V
VI	8.3		47.5	10.5		48.2	11.5		48.0	VI
VII	5.1	18.7		6.4	22.6		6.7	23.2		VII
VIII	5.3			4.7			5.0			VIII
IX	4.1	13.6		4.2	14.2		3.6	12.2		IX
X	4.9			4.7			4.0			X

Fig. 5. Number of days needed for reaching the values of M-day discharges
Station : Ivancice, River : Jihlava

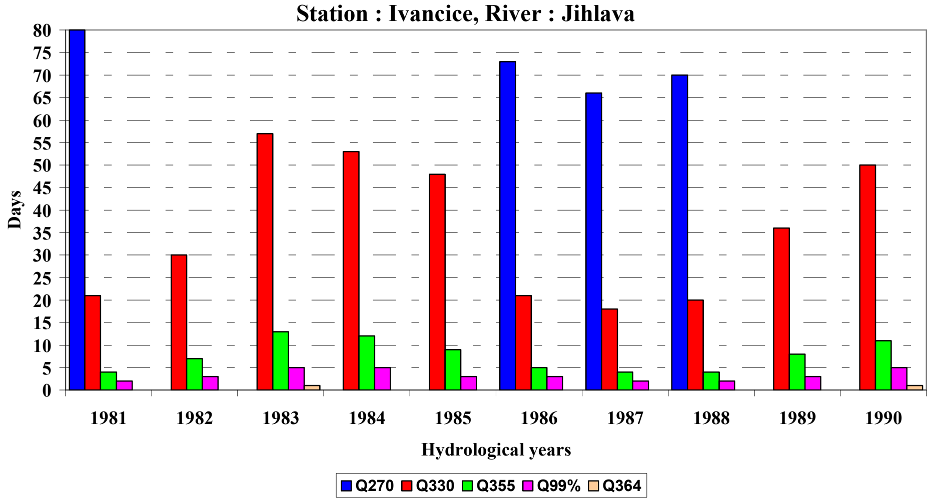

Table 2. Number of days needed for reaching the values of M-day discharges, STATION : Ivancice RIVER : Jihlava					
Hydrological year	M-day discharges				
	Q_{270}	Q_{330}	Q_{355}	$Q_{99\%}$	Q_{364}
1987	66	18	4	2	
1988	70	20	4	2	
1981	80	21	4	2	
1986	73	21	5	3	
1982		30	7	3	
1989		36	8	3	
1985		48	9	3	
1984		53	12	5	
1983		57	13	5	1
1990		50	11	5	1

Fig. 6. Number of days needed for reaching the values of M-day discharges
Station : Kyjov, River : Kyjovka

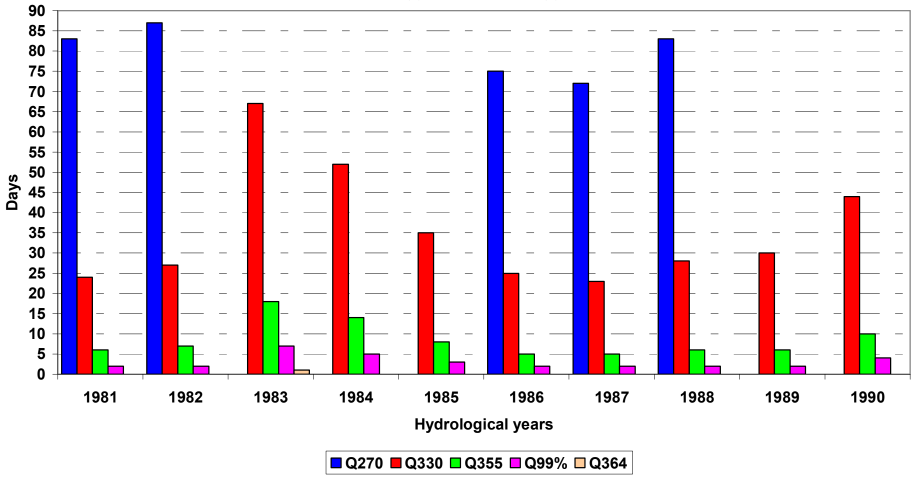

Table 3. Number of days needed for reaching the values of M-day discharges, STATION : Kyjov RIVER : Kyjovka					
Hydrological year	M-day discharges				
	Q_{270}	Q_{330}	Q_{355}	$Q_{99\%}$	Q_{364}
1987	72	23	5	2	
1986	75	25	5	2	
1988	83	28	6	2	
1989		30	6	2	
1981	83	24	6	2	
1982	87	27	7	2	
1985		35	8	3	
1990		44	10	4	
1984		52	14	5	
1983		67	18	7	1

Fig.7. Number of days needed for reaching the values of M-day discharges
Station : Straznice, River : Velicka

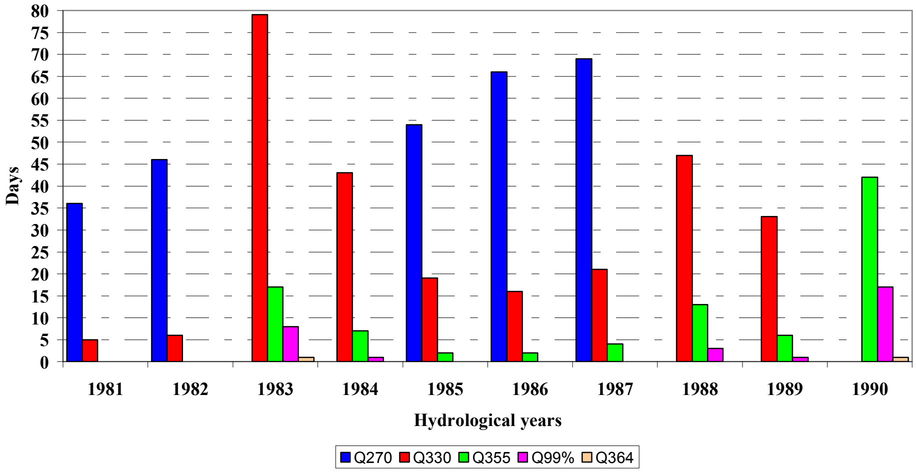

Table 4. Number of days needed for reaching the values of M-day discharges, STATION : Strážnice RIVER : Velička					
Hydrological year	M-day discharges				
	Q_{270}	Q_{330}	Q_{355}	$Q_{99\%}$	Q_{364}
1981	36	5			
1982	46	6			
1986	66	16	2		
1985	54	19	2		
1987	69	21	4		
1989		33	6	1	
1984		43	7	1	
1988		47	13	3	
1983		79	17	8	1
1990			42	17	1

Table 5. Number of days needed for reaching the values of M-day discharges and number of events when the proper M-day discharge was not reached or was not decreased

M-day discharge	Number of days/ Events not reached or not decreased	Hydrological year									
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Q_{270}	Number of days	36-88	46-90	-	-	54-82	37-88	41-80	70-85	84-88	-
	Not reached	4	5	12	12	5	0	0	4	9	11
Q_{330}	Number of days	5-60	6-36	37-79	30-66	19-48	9-29	11-28	20-47	24-50	37-60
	Not reached	0	0	2	0	0	0	0	0	0	1
Q_{355}	Number of days	2-22	4-8	9-30	4-15	2-8	2-6	1-7	3-13	4-13	6-42
	Not decreased	1	1	0	0	0	1	0	0	0	0
$Q_{99\%}$	Number of days	1-7	1-4	4-18	1-6	1-4	1-3	1-4	1-3	1-5	2-17
	Not decreased	2	2	0	1	2	3	2	1	1	0
Q_{364}	Number of days	1	-	1	-	-	-	-	-	-	1
	Not decreased	11	12	2	12	12	12	12	12	11	4

Table 6. Rate of runoff of hydrological years 1981-1990

Hydrological year	Related to 1981-1990		Related to 1924-2007	
	Rate of runoff	Exceedance probability p [%]	Rate of runoff	Exceedance probability p [%]
1981	mean	50.0	mean	49.4
1982	wet	25.5	wet	24.5
1983	dry	64.5	dry	64.8
1984	dry	83.2	dry	85.0
1985	wet	24.1	wet	23.3
1986	wet	21.2	wet	21.0
1987	extremely wet	5.3	extremely wet	4.4
1988	wet	35.6	wet	34.0
1989	dry	77.5	dry	76.7
1990	extremely dry	97.6	extremely dry	98.0

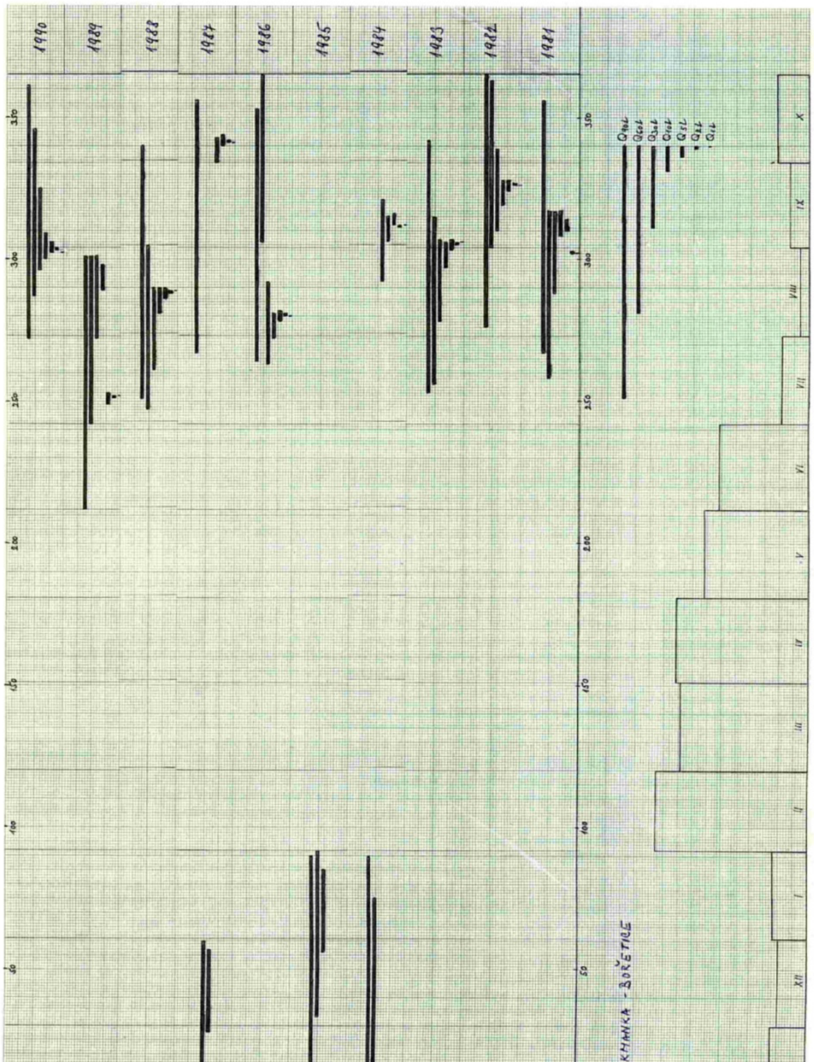

Fig. 8. Low discharges occurrence. Station : Boretice, River : Trkmanka

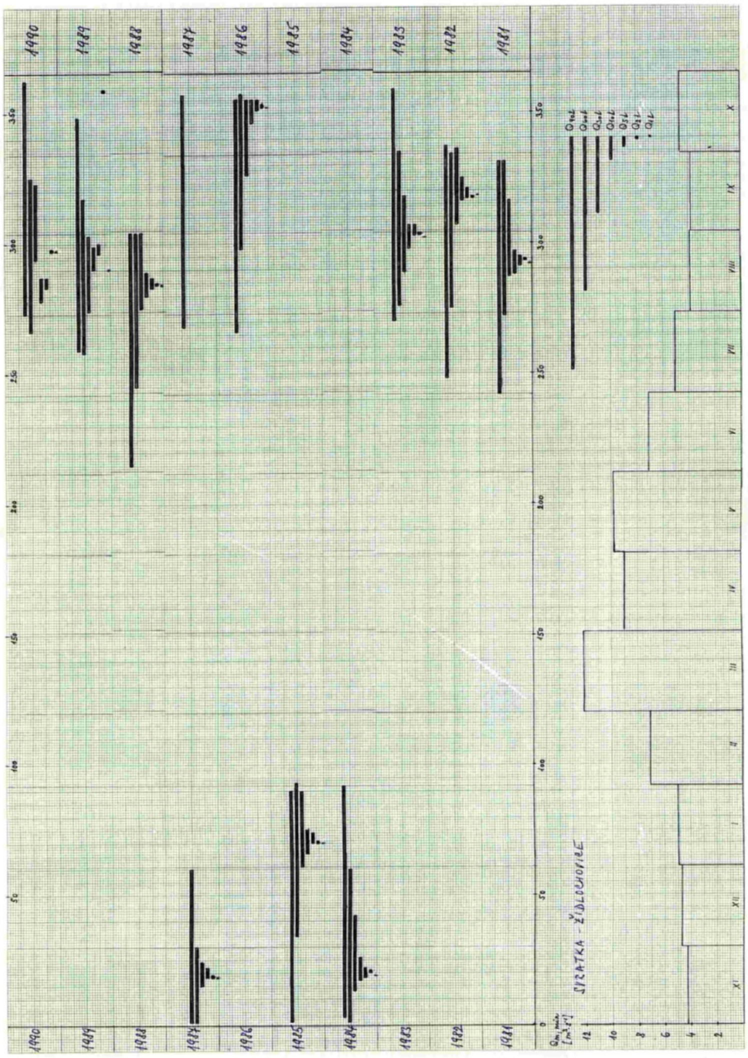

Fig. 9. Low discharges occurrence. Station : Zidlochovice, River : Svratka

Table 7. Extremely dry and dry hydrological years during 1981-2007, Station : Ivancice, River : Jihlava

Hydrological year	Related to 1924-2007	
	Rate of runoff	Exceedance probability p [%]
1991	extremely dry	99.2
1990	extremely dry	98.0
1993	extremely dry	95.6
1984	dry	85.0
1998	dry	82.6
1994	dry	81.4
1995	dry	80.2
1992	dry	77.8
1989	dry	76.7
2007	dry	74.3
1983	dry	64.8
2001	dry	61.3